# EMERGING WEB-BASED 3D GRAPHICS
# FOR EDUCATION AND EXPERIMENTATION

**Curtis Blais, Don Brutzman, Jeffrey Weekley, and LT James Harney, USN**
**Naval Postgraduate School, Monterey California**
*clblais@nps.navy.mil   brutzman@nps.navy.mil*

## ABSTRACT

The purpose of this paper is to describe current work in the evolution of open standards for 3D graphics on the World Wide Web (*Web3D*) and to provide examples of application of emerging Web3D authoring, visualization, and simulation tools for military education and experimentation.  The paper presents an overview of the current state of Web3D standardization activities, including establishment of conformance tests and a reference implementation.  The paper describes examples of the application of web-based 3D graphics for exploring complex military battlespaces supporting Limited Objective Experiments in Anti-Terrorism / Force Protection (AT/FP) and emerging joint command and control concepts for Web-based information management.

In February 2002, the Web3D Consortium (www.web3d.org) announced completion of the draft of the X3D (Extensible 3D) specification, the proposed next-generation standard for describing 3D content on the World Wide Web (http://www.web3d.org/x3d.html).  X3D is a scene graph architecture and encoding that improves on the Virtual Reality Modeling Language international standard (VRML 97, ISO/IEC 14772-1:1997).  X3D uses the Extensible Markup Language (XML) to express the geometry and behavior capabilities of VRML.  The paper provides a brief overview of X3D and the current status of the standardization process and supporting efforts (e.g., development of an open source scene authoring and visualization tool and conformance test suite development), updating information presented in the I/ITSEC 2001 paper and conference briefing.

To demonstrate the capabilities of the emerging X3D standard, the Naval Postgraduate School is performing research toward development of scenario authoring and Web-based visualization capabilities. The paper describes the current status of research activities, including application of web-based 3D graphics to a Navy Force Protection Limited Objective Experiment (LOE) conducted in April 2002 and a Joint Futures Laboratory LOE investigating peer-to-peer Joint Interactive Planning concepts. The paper discusses technical challenges in representing complex military operations in Web environments and describes work in progress to demonstrate application of Web-based technologies to create and explore complex, multi-dimensional operational scenarios. The paper concludes with discussion of future research directions for application of web-based 3D graphics in military education, training, and experimentation.

## ABOUT THE AUTHORS

**Curtis Blais** is a Research Associate at the Naval Postgraduate School, with joint faculty appointment to the Institute for Joint Warfare Analysis (IJWA) and the Modeling, Virtual Environments, and Simulation (MOVES) Institute. His principal research areas at NPS include Web-based 3D graphics for military education and training, Web-based instruction, and design of multi-agent simulations. Prior to coming to NPS, Mr. Blais spent 25 years in software development in industry and government working on Navy and Marine Corps command staff training systems and C4I simulations. He designed and developed combat models for several generations of Marine Corps systems, and continues to provide technical consultation to the Marine Corps for design of the next-generation command staff training system, the Joint Simulation System (JSIMS). Mr. Blais has a B.S. and M.S. in Mathematics from the University of Notre Dame, and is working toward a PhD in MOVES at the Naval Postgraduate School.

**Don Brutzman** is Assistant Professor at the Naval Postgraduate School in the Modeling, Virtual Environments, and Simulation (MOVES) Institute and the Undersea Warfare Academic Group. Dr.

Brutzman's research efforts include 3D real-time virtual worlds and 3D visualization of sonar signals and autonomous underwater vehicles (AUVs); machine learning, sensing, perception, and control; and distributed audio, video, and graphics applications using multicast, distributed interactive simulation, and adaptive protocols for large-scale virtual environments. Dr. Brutzman is leading efforts in the Web3D Consortium to develop next-generation Web3D specifications and tools. Dr. Brutzman served 20 years in the U.S. Navy as Electrical Officer, Combat Systems Officer, and Navigator aboard submarines, and was Operational Test Director for testing of the MK 1 Combat Control System (CCS) and Mk 48 Advanced Capability (ADCAP) torpedo. Dr. Brutzman obtained a B.S. in Electrical Engineering at the U.S. Naval Academy and a M.S. in Computer Science at the Naval Postgraduate School. Dr. Brutzman received a PhD in Computer Science, with a minor in Operations Research, from NPS in 1994.

**Jeffrey Weekley** is a Research Associate at the Naval Postgraduate School with the Modeling, Virtual Environments, and Simulation (MOVES) Institute. His principle research areas at NPS include Web-based 3D graphics for military applications and development and implementation of computer simulations and software interfaces for Autonomous Underwater Vehicles (AUVs). Before joining NPS, he worked at ROLANDS & ASSOCIATES Corporation in 3D content development, web graphics research and technical writing for simulation and modeling efforts. He is a former Navy Cryptolinguist. After leaving the Navy, he worked as an Operations Analyst in the biotech, semiconductor, aerospace and pharmaceutical industries. He has a degree in Communications from the University of Northern Iowa and two degrees in linguistics from the Defense Language Institute, Monterey, California.

**LT James Harney**, United States Navy, is a student at the Naval Postgraduate School completing a M.S. in Computer Science. His thesis research involves the utilization of X3D Web-based graphics and software agent technologies to gain insight into planning and evaluation of Anti-Terrorism and Force Protection measures for U.S. Navy warships. Prior to coming to NPS, LT Harney served as commissioning Damage Control Assistant in USS ROSS (DDG 71) followed by a tour as Combat Information Center Officer in USS PETERSON (DD 969). LT Harney earned a B.S. in Computer Science from the U.S. Naval Academy in 1996. Following graduation from NPS in March 2003, LT Harney will be assigned to Surface Warfare Officer's School in Newport, Rhode Island for department head training.

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## PREFACE

The Internet and World Wide Web is providing an information resource of unrivaled breadth available to all at little or no monetary and technical investment. Through various initiatives, the United States Government is employing this vast domain to improve services across multiple fronts to benefit citizens at large as well as military and civilian employees in particular. As part of these initiatives, research is in progress to identify opportunities for enhancement of information management, presentation, education, and analysis through application of Web-based 3D graphics. Integration of 3D graphics into the World Wide Web continues to be an extraordinary area for opportunistic growth.

The Web3D Consortium is an international organization established to define and promote standards for 3D graphics representation on the World Wide Web. The Consortium is developing specifications for the next generation standard, Extensible 3D (X3D), for international review and approval. Once approved, the X3D standard will become the foundation for all X3D content on the Web. Furthermore, the organization is supporting development of conformance tests and an open-source reference implementation to provide a basis for community understanding of the specifications, from which both commercial proprietary and freely available implementations may be developed to further promote and extend use of the standard world-wide.

As a major participant in the Web3D Consortium and contributor to the Web3D standardization process, the Naval Postgraduate School (NPS) is pursuing a broad-based strategy for exploitation of World Wide Web technologies to support military modeling and simulation for education, analysis, and war fighting. Under initial funding from the Defense Modeling and Simulation Office, NPS launched the Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE) project in mid-2000. The purpose of the SAVAGE project is to create authoring tools and techniques to generate interactive, multi-user, web-based 3D models of military operations. Foundational work at NPS and early work in the SAVAGE project focused on representation of 3D models and behaviors for visualizing communications plans (Laflam, 2000; Hunsberger, 2001), coordination of humanoid teams (Miller, 2000), air tasking orders (Murray and Quigley, 2000), and amphibious operations orders (Nicklaus, 2001). These efforts were then extended to reconstruction of actual events, including: the USS Greeneville/Ehime Maru collision off the coast of Oahu, Hawaii (Blais, et. al., 2001); the USS COLE terrorist attack in Aden Harbor, Yemen (Blais, et. al., 2002a); and Autonomous Underwater Vehicle (AUV) mine-hunting test tracks (Weekley, 2002).

Most recently, the project has supported Web-based 3D visualization for two Limited Objective Experiments (LOEs), a Peer-to-Peer Communications experiment (P2P LOE) conducted at the Naval Postgraduate School for the Joint Futures Laboratory (Pilnick et al., 2002) and an Anti-Terrorism / Force Protection (AT/FP) experiment. The former builds upon AUV track reconstruction work (Weekley, 2002), while the latter builds upon experience gained from the earlier USS COLE scenario reconstruction work (Blais, et. al., 2002b). These efforts demonstrate not only the power of the scene graph representation in the X3D language, but also application of the growing collection of Web-based software tools for the Extensible Markup Language (XML) to manipulate the information in the X3D scenes and benefits of 3D visualization for military operations planning, experimentation, and analysis.

The activities of the Web3D Consortium, X3D specification status, and the SAVAGE project were introduced in a paper and presentation at I/ITSEC 2001 (Blais, et. al., 2001). The current paper provides an update to that introduction, describing current status of specification efforts

and development of the open-source X3D reference implementation. To emphasize the potential of the technology to support military education and experimentation in Web-based environments, the paper presents techniques models, and scenarios from the P2P and AT/FP LOE applications introduced above.

## WEB3D CONSORTIUM

The Web3D Consortium Incorporated is a nonprofit organization dedicated to the creation of open standards, specifications and recommended practices for Web3D graphics (for a full description, see http://www.web3d.org). From the perspective of the Web3D Consortium, "Web3D" is an overarching term to describe protocols, languages, file formats, and other technologies that are used to deliver compelling 3D content over the World Wide Web (Walsh and Bourges-Sevenier, 2001). The Web3D Consortium's charter goal is to accelerate the worldwide demand for products based on these standards through the sponsorship of market and user education programs. Through various open Teams and Working Groups, consortium members and the 3D-graphics community focus on Web3D standards and technologies to promote evolution of capabilities that will help bring Web3D into the mainstream of online experience.

### Virtual Reality Modeling Language (VRML 97)

Through the mid-1990's, the Web3D Consortium worked with the Virtual Reality Modeling Language (VRML) community to develop specifications for versions 1.0 and 2.0 of the VRML language. VRML is a language for describing 3D scenes as a *scene graph*; i.e., a hierarchical decomposition of the renderable components in a scene. Expressed as text, VRML files are readily accessible over the Internet and can be written and modified using simple text editing software (Brutzman, 1998; Ames, Nadeau, and Moreland, 1997). In 1997, the International Standards Organization (ISO) established the VRML specification as an international standard. Subsequently, VRML has enjoyed widespread use as a Web3D graphics language through numerous implementations (e.g., Nexternet Piveron, Parallelgraphics Cortona, Blaxxun Contact) available as plug-ins for common Web browsers (e.g., Microsoft Internet Explorer, Netscape Navigator). VRML is also widely used as a 3D graphics interchange file format.

### Extensible 3D (X3D)

The next-generation specification for VRML is the Extensible 3D (X3D) standard (see http://www.web3d.org/x3d.html). X3D is a scene graph and text-based encoding designed to

overcome several limitations of the VRML standard. X3D uses the Extensible Markup Language (XML) to express identical VRML geometry and behavior structures, and is therefore a backwards-compatible XML tagset for describing the VRML 200x standard for Web-capable 3D content. Such content is not static but dynamic, driven by a rich set of interpolators, sensor nodes, scripts, and behaviors. Comparison of VRML and X3D scene graph representations was provided in (Blais, et. al., 2001).

The X3D Working Group within the Web3D Consortium is tasked with the design, development, evaluation, and standardization of the X3D/VRML 200x specification. This group works with others in the community to define the functional and technical content of the language, documented in a specification for community review and consensus. In February 2002, the Web3D Consortium announced completion of the draft of the X3D (Extensible 3D) specification. The next major step is submission of the specification to the ISO for approval.

In June 2002, X3D was presented as a New Project (NP) proposal to the ISO/IEC Subcommittee 24 (SC24, Working Group 6; http://www.sc24.org/) (Reddy, 2002). After a strawman vote, all of the attending national bodies stated they would support the X3D NP. The X3D NP request will go out for letter ballot to all national bodies. Five national bodies need to vote positively and to indicate participation in the project in order for it to pass. At the meeting, four national bodies indicated that they would vote for and participate in X3D. It was believed that both Germany and the Czech Republic would also vote this way, which will allowing the X3D NP to pass. Following this step, the specification will enter a 2-year timeline for approval as an international standard.

## X3D DEVELOPMENT

In parallel with efforts to draft the X3D specification, the Working Group is developing a reference implementation as a proof of concept and basis for future development. This work entails both development of XML representations of the language constructs, partitioned into component layers for different categories of users (from extremely "light-weight" components with minimal essential language features to "heavy-weight" components with extended language features, such as multi-user networking support), and implementation of an open-source browser for authoring and visualizing scenes.

The current X3D/VRML 200x XML implementation is capable of compatibly using all legacy VRML 97 content through a VRML-to-X3D translator developed by the National Institute of Standards and Technology (NIST). X3D provides new interoperability with other relevant standards including MPEG-4 and an entire family of XML-based languages. X3D further addresses several shortcomings of VRML 97, provides tighter media integration, improved visual quality through advanced-rendering nodes, and enables a component-based approach. Combined binary and geometric compression has been deferred until other X3D deliverables are complete.

## Conformance Test Suite

An extensive set of conformance examples has been created to enable browser companies and users to validate both content and rendering capabilities. The Web3D VRML/X3D Conformance Test Suite integrates a body of work that originated from NIST VRML97 Conformance Suite, and adds several new tests for new nodes. Those tests are now available in XML format, allowing the tests to evolve with the VRML and X3D specifications. The test suite, consisting of approximately 850 tests, allows a viewer to evaluate a VRML/X3D browser by simply browsing through a CD (or online directory) of documented tests. Tests are organized by node group functionality (for example Geometry, Lights, Sounds) and include tests of browser state, field range testing, audio/graphical rendering, scene graph state, generated events, and minimum conformance requirements. Each test consists of an XML (X3D) file, its equivalent VRML97 file, plus an HTML "pretty print" version of the XML content for inspection. Also included with each test is a complete description of initial conditions and expected results. In addition, "sample results" in the form of .jpg or .mpg video are also provided via hyperlink to give the tester a complete "picture" of a successful test result.

The full power behind the X3D representation is in the underlying XML technology. As an XML document, the 3D scene is simply structured data, which can be processed in a variety of ways without concern for how the data should be presented. In this case, the X3D file describes

3D content, but that content need not be rendered as a 3D scene. Through Extensible Stylesheet Language Transformation (XSLT; see Deitel, Deitel, Nieto, Lin, and Sadhu, 2001), the content in an X3D/XML file may be converted to VRML, pretty-printed to HTML, or converted to any number of other formats (including objects expressed as source code). As stated in the I/ITSEC 2001 paper (Blais, et. al., 2001), expression of VRML scenes in XML enables application of a wide range of existing and emerging XML-based tools for transformation, translation, and processing. XML is rapidly transforming the Web from a vast document repository to a vast data repository (Goldfarb and Prescod, 2001). XML provides numerous benefits for extensibility and componentization. It is also important to note that XML forms the infrastructure of the Web-Enabled Navy Architecture (Task Force 'W', 2001), providing the link between data content, applications, and presentation. For X3D, XML further provides the ability to develop well-formed and validated scene graphs, an extremely valuable constraint since "broken" 3D content would no longer be allowed to escape onto the Web where it might cause larger scenes to fail.

## Xj3D Open Source

The Web3D Consortium maintains an open-source project written in Java called Xj3D. The primary goals of the project are to provide a freely available implementation of the X3D graphics specification as well as backwards compatibility with the ISO Vrml97 specification. The open source implementation allows both DoD and commercial organizations to incorporate and modify the code-base in a non-restrictive manner.

Work at NPS has incorporated the Xj3D code-base as a VRML97 and/or X3D content loader in a Java3D framework based application environment known as NPSNET V. Figure 1 depicts the 3D visualization of an AT/FP Scene rendered using the code-base. Additionally, since the X3D graphics standard is extensible by allowing an author to define, implement, and deploy capabilities not found in the specification, the Xj3D developers have demonstrated the ability to incorporate 2D mapping overlays, bumpmap texturing, and other graphical techniques within the X3D specification and rendering through the use of Xj3D.

In addition to its utility as a loader/renderer within Java3D, the Xj3D project is also intended to be used as a VRML or X3D browser similar to the commercially available plug-ins (such as Pivoron, Cortona, etc.).

Although Xj3D is not yet complete, major releases of the software are provided to the community for testing and familiarization at approximately 6-month intervals. The Milestone 4 version of Xj3D was released at the annual Web3D Symposium in Tempe, Arizona in February 2002, and the Milestone 5 version was released at SIGGRAPH 2002 in San Antonio, Texas in July 2002. Developer snapshot releases occur in-between the major releases and all current source code is available through a CVS server located at: http://web3d.metrolink.com.

As the Xj3D implementation becomes more complete, past difficulties experienced with the attempted widespread deployment and use of VRML97 content should be overcome allowing one to better utilize the Web for scaling to larger audiences in both training and education.
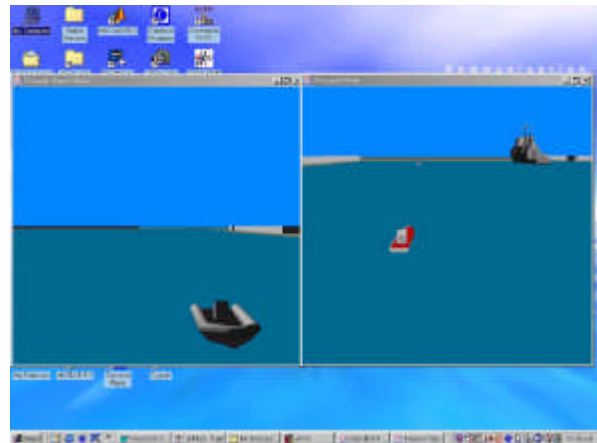


Figure 1. An X3D scene from the AT/FP scenario rendered in the NPSNET V framework using the Xj3D code-base.

## X3D IN MILITARY EDUCATION AND EXPERIMENTATION

NPS students and faculty are engaged in a number of projects and studies involving use of 3D visualizations in multi-user, interactive Web-based environments. The emerging X3D standard is used for these efforts to explore and

exploit XML-based information technology tools and techniques while also providing complex and sophisticated testing of the X3D scene graph constructs. Each year, approximately 50 military students across several different curricula (e.g., MOVES, Computer Science, Operations Research, Physics, Information Technology, and others) attend introductory and advanced X3D courses at NPS. In each course, the students develop 3D models and dynamic, interactive scenes for class projects, some of which may be directly related to or supporting student thesis work (LT Harney's AT/FP modeling is an excellent example). Largely through student efforts, the school has developed a large library of 3D military models and authoring tools that can be reused to create ever more increasingly complex scenarios. The following paragraphs describe two significant efforts, one completed and one in progress, from the first half of calendar year 2002 to illustrate the application of X3D to create Web-based 3D visualizations supporting military experimentation.

**Peer-to-Peer Communications LOE**

In support of the Peer-to-Peer (P2P) LOE sponsored by the Joint Futures Laboratory, NPS created a web-based 3D visual reconstruction of the scenario. The objective was to create a 3D model of the portion of the NPS campus where the experiment was conducted, together with graphical representations of the movement of student teams and their sightings as the scenario played out. The resulting dynamic playback scenes would be available in a form that could be readily shared across the network and viewed in standard browsers (Internet Explorer, Netscape Navigator) using freely available 3D plug-ins.

The setting for the P2P LOE was the NPS central Quadrangle, and consisted of several teams tasked with forward observation of an artificial hostage rescue scenario. It was not the intent of the scenario designers to replicate accurately the tactics and events of an actual hostage rescue operation. Instead, the purpose was to give the LOE some context or back-story, making events and motivations more understandable and stimulating to the participants.

The goals of the experiment included creating a sense of shared situational awareness among the peer teams and a reach-back facility by using technologies other than reliance on voice communications alone. Reconnaissance and Surveillance Teams (RSTs) used chat, map views and the Internet to achieve this objective. In the LOE, web-based 3D visualization was used to recreate the scenario as it played out and was not used in situ or during planning. We believe there is great promise in using 3D visualizations to augment the other means of establishing situational awareness during an operation, as well as for scenario planning and reconstruction of scenario events for review and analysis.

Key tools used in the P2P LOE reconstruction effort included:

- X3D-Edit, a scene graph editing tool configured for X3D using the IBM Xeena XML editor for authoring the 3D models and aggregate worlds (http://www.alphaworks.ibm.com/tech/xeena),
- A Java-based translator program from the NIST to convert existing VRML97 models into X3D.
- A custom, Java-based tool to convert the data generated by the participants into 3D tracks which animate object entities in the 3D world.

The Java program for converting track data to 3D visualization was an adaptation of track visualization software developed at NPS and employed in late 2001 for AUV mine warfare experiments (Weekley 2002).

Models of the campus buildings were developed several years ago for a previous NPS project. These were in a proprietary commercial product format, but the product provided the capability to export to VRML format. The models were then converted to X3D using the tool provided by NIST. In X3D format, the products could be readily integrated into more complex scenes.

To construct the 3D model of the area of the campus that would be used in the P2P LOE, a physical survey of the Quadrangle was performed. This survey identified distinctive trees, shrubs, succulents and other small plants, fire alarms, pedestrian barricades, bicycles, bike rack, WWII-era contact mine display, fire hydrant, benches, picnic tables, "Thai Hut" food vendor trailer, phone booth, clock, satellite dish, as well as the buildings around the area. In the final reconstruction, models of the following objects were used (see Figure 2): Root Hall, Spanagel Hall, Bullard Hall, Halligan Hall,

Ingersoll Hall, Hermann Hall, Mechanical Engineering Building, Sidewalks and Roads, Satellite Dish, Street Lamp, Green Bench, Contact Mine, Thai Hut food stand and Parasol, Picnic Table, Free Standing Fire Alarm, Fire Hydrant, Phone Booth, Wooden Bench, and a Low Wooden Bench.
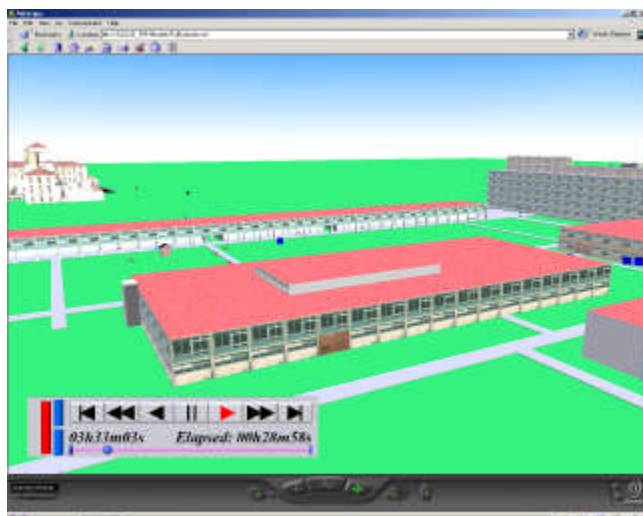


**Figure 2**. Virtual NPS Quadrangle with scenario playback control.

Because the 3D visualization needed to show the operation from perspectives not otherwise available, it was determined that the 3D campus should be built free of vegetation. This "tree-free" environment is still easily recognizable and allows for unobstructed observation from various vantage points in the scene. Foliage and natural forms can be difficult to author and represent. The high polygon count of a single, realistic looking tree could reduce graphics rendering performance to the point of annoyance. While simplistic models could be created, it is questionable whether they would add significant value to the scene if they were not sufficiently detailed to give good indication of clear and obstructed lines of sight. Moreover, it was decided that tree and foliage models would not display well on handheld devices such as those used by the RST members in this LOE. An area of future work would be to create a visualization allowing the user to selectively display or not display trees and foliage in the scene, possibly in user-specified regions of the scene or for particular lines of vision.

A major aspect of the Peer-to-Peer communication infrastructure was the wireless LAN installed across the Quadrangle for the experiment. This was a combination of six wireless hubs and antennas. The coverage was purposefully spotty in order to investigate network traffic effects as teams entered and left coverage areas. To survey the experiment area, the Quadrangle was divided into 50 square meter sections, and signal strength was measured in each section. A graphical depiction of the signal strength in the area of coverage was created from the survey data. The resulting visualization served as the basis for a decision to place an additional wireless hub to provide somewhat better coverage of the region. Measurements were taken again, and the resulting signal visualization is shown in Figure 3.
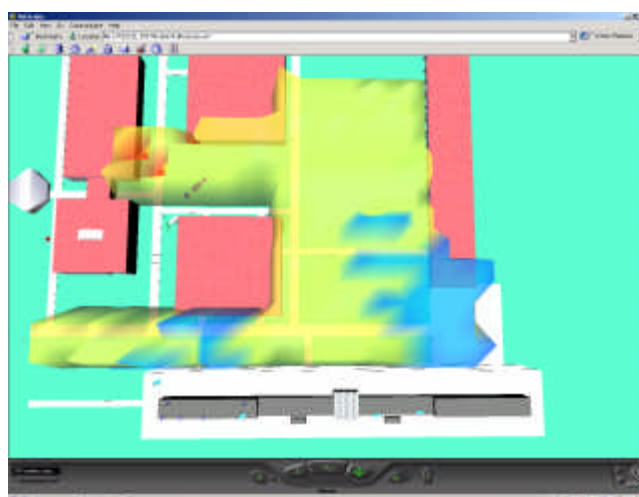


**Figure 3.** Wireless LAN signal strength visualization (from above).

The signal strength is indicated both by color and by height of the coverage region (i.e., poor signal strength is visualized in red at 10-meter height; moderate strength is visualized in yellow at 30-meter height; good signal strength is visualized in blue at 50 meter height).

During the 3.5 hours of the LOE execution, the Operations Center recorded over 20 Megabytes of data on own-team positions, situation reports, and sightings into a Microsoft Access database. Timestamped position data were extracted and used to generate movement paths for the teams. The resulting 3D visualization (for example, Figure 4) provides representations of the RSTs, terrorists and bombs, similar to the 2D representations used in LOE planning and scenario execution, but with the added dimension of time. Analysts could

replay the experiment to see where each team was at any point in the experiment and what information each team held at that time.
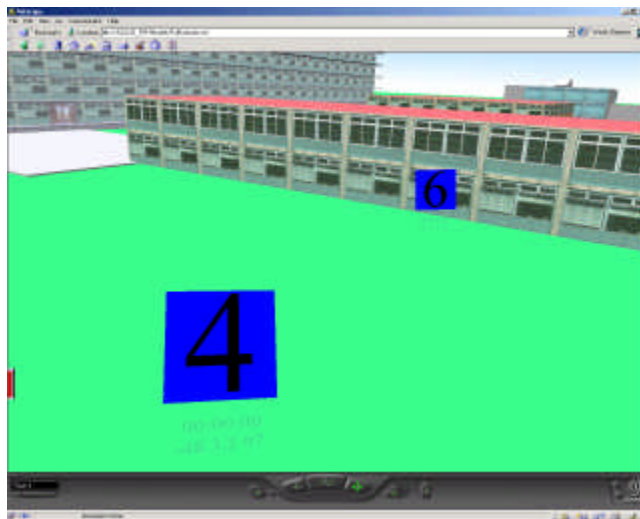


**Figure 4**. Team 4 and 6 icons positioned within the localized coordinate system.

If the status of an object is reported accurately in near real time, it can be represented accurately in a distributed, multi-user 3D world, using the DIS-Java-VRML methodology for networked, interactive 3D simulations. The challenge is obtaining accurate reporting of the status of a real object, and then registering that location appropriately in the local coordinate system of the 3D scene graph.

A key enabler in the reconstruction of the LOE scenario was re-use of existing 3D models through the NIST translation tool. As stated earlier, the international VRML standard continues to be a valuable 3D scene interchange format for multiple applications, including support for web-based 3D visualizations. In addition, development of software to convert from the raw data files into text-based X3D file formats was straightforward. Such automated techniques demonstrate the power and simplicity of the XML standard for Web-based data interchange.

This work further demonstrated that the generation of meaningful 3D worlds for Web-based distribution is becoming practical for a wide range of applications. There is significant potential for using the 3D visualizations in LOE planning, allowing the planners to "walk through" the timeline and major scenario events within the 3D world. Moreover, 3D visualization of the

scenario area would have enriched the team and participant training sessions, particularly for those participants not familiar with the NPS campus. Given a reliable data stream of position information and sightings during conduct of the scenario, it is feasible for the 3D visualization to be updated near-real time, so as to augment the 2D situation displays that were provided in the Operations Center and on RST devices.

Visualization of the signal strength across the physical LOE area (Figure 3) demonstrated the potential to visualize aspects of a problem not normally visible to planners and participants

The other quality of the Web3D visualization that was not exploited during the P2P LOE is its Web-based capability. As an XML representation of the scene graph, the X3D models developed for the P2P LOE reconstruction are simply text files that are readily exchanged over networks, and can be viewed in common Internet browsers (using freely available 3D plug-ins). The dynamic 3D visualizations could be viewed in near-real time by the participants on the network. Moreover, as an XML file, the information in the scene is simply data which could be converted through stylesheet transformations into other formats.

**Anti-Terrorism / Force Protection LOE**

U.S. Naval forces have increasingly been at greater risk while deployed to foreign ports and harbors over the past decade. To continue to carry out the National Military Strategy of *engagement* with foreign countries through the navy, increased focus has been placed on the application of non-traditional non-lethal weapons along with new doctrinal development in order to ensure the security of our forces. The SAVAGE research group has taken a two-pronged approach in this arena: (1) conduct research and development in a Web context utilizing agent technologies to assist the analysis of LOE execution for the testing and evaluation of new weapons types; (2) provide a prototype tool for training and planning against the surface threat that can be expanded and utilized by fleet units.

A near term application for this emerging tool is an upcoming Force Protection LOE (note: had been previously scheduled for August 2002, but at the time of this writing had been postponed indefinitely). LOE planners requested development of a visualization of the planned

area of operations and primary scenario events for pre-experiment planning and post-experiment reconstruction. Creation of a fixed set of scenario events, or even reconstruction of actual events, cannot fully address "what-if" questions of interest in an AT/FP scenario. For this reason, agent-based technologies have been incorporated within the research to allow a wide-spectrum of potential outcomes to be investigated, enabling the analyst to gain further insights towards solutions or vulnerabilities for the problem under analysis. In effect, the Web3D virtual environment becomes a laboratory for deeper investigation of both the planned and actual scenario events, as well as the "could have happened" events.

Earlier project efforts developed authoring tools and techniques for reconstruction of the Al-Qaida sponsored terrorist attack on the USS COLE (DDG 67) in Aden, Yemen in October 2000. The steps performed for that effort are provided a foundation for the AT/FP LOE work, presenting models and modeling techniques that were reused for the FP LOE; namely:

- Creation of the land and sea space encompassing the area the major events occurred.
- Creation of the pier and other structures to which the COLE (or other ship of interest) was moored.
- Creation of the various ships and small craft that played a role in the events that day.
- A visual representation of physical explosive effects to maintain scientific validity as closely as possible.
- Animation of all entities within the scene as portrayed in the Court of Inquiry (or other source materials that may be available).
- A means of allowing the user to control the animation (stop, play, rewind, etc.) as he views the simulation. Additionally, since the events modeled encompassed over three and one-half hours of scenario time, the user would require a means of fast-forwarding to points of interest or to reset the play-back to an earlier time as desired.

For the reconstruction of the Land and Sea Space, Digital Terrain Elevation Data (DTED) Level 1, providing terrain elevation postings at approximately 100 meter intervals, was considered to be sufficient for our modeling purposes. For the COLE reconstruction (Figure 5) and AT/FP scenario, we chose to create sufficient land and sea space to reconstruct events from the beginning of the transit into the port. Of course, the size of the area to be represented depends on the locations and movement of entities participating in the scenario.

Models of physical structures (e.g., refueling dolphin in the COLE scenario; pier side buildings in the AT/FP scenario) important to the scenario were generated using the X3D-Edit tool described previously. Due to the existence of the freely available SAVAGE online model library (see http://web.nps.navy.mil/~brutzman/Savage), many unclassified military models of interest exist that allow the author to focus on the modeling and simulation of entity relationships rather than the geometric modeling. Figure 6 is a depiction of the Arleigh Burke class Destroyer model utilized in the reconstruction of the COLE attack. Various other models from the Savage library were utilized in addition to the creation of various low-resolution small boat entities that played a role in the scenario. It is important to note, however, that while "photo-realism" can be achieved with visual model content, it has been generally desirable to create models that correctly represent the geometry of a craft so that it can be recognized and then utilized in physical based simulation rather than investing undue time and effort in creating extremely high visual realism. In general, that level of visual realism is not needed for the planning and analysis efforts targeted for this work. More important is the accuracy of the event timelines and object behaviors.
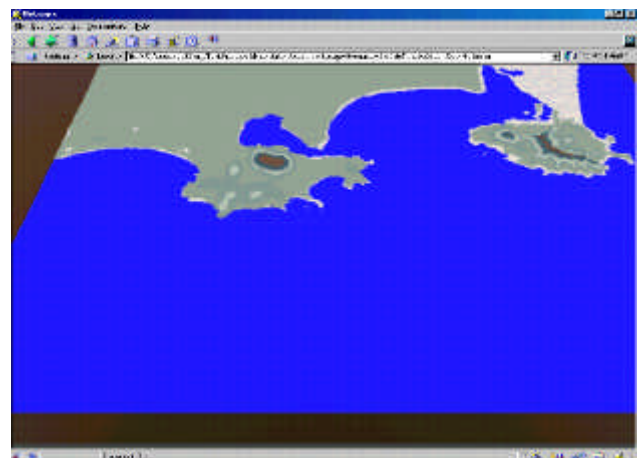


**Figure 5**. VRML97 rendering of the X3D representation of Aden Harbor, Yemen.

To model explosions, we used the U.S. Army's unclassified TNT equivalency model to represent the various ranges of damage that occur. An unclassified failure rate of steel was utilized to determine three levels of damage (structural failure, severe damage, and light damage). Each range was then represented through the use of different colored spheres that would allow the analyst to have a visual indication of the effectiveness of an attack while viewing the simulation (Figure 7). Although a more realistic appearing explosion might look better, it would give less insight to an observer of the simulation as to what the real effects of an explosion might be, or in the case of the COLE, what the actual effects were. By designing the explosion model as an X3D prototype, it is now available in the SAVAGE library for reuse or extension in LOEs or other projects.
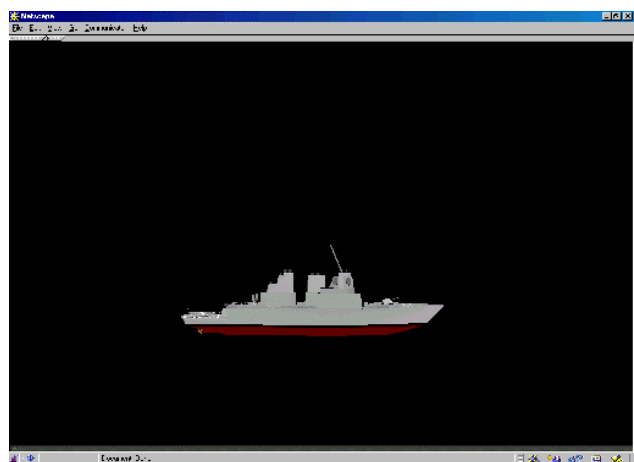


**Figure 6**. VRML97 rendering of the X3D representation of an Arleigh Burke Class Destroyer model from the SAVAGE model library.
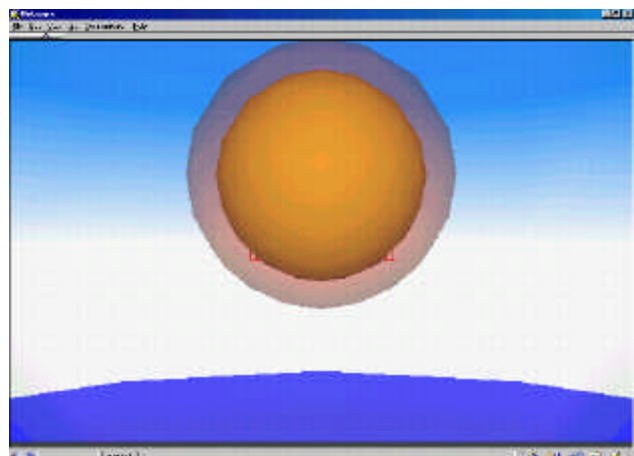


**Figure 7**. Physically-based explosion prototype from the SAVAGE model library.

Realistic animation of entities in scenario reconstruction can prove to be a difficult task when one considers the various factors that have to be taken into account in a 3D simulation representation (e.g., 6 degrees of freedom and physically-based modeling for all entities that are being portrayed). Smooth yet accurate animation of entities transitioning through a course change can prove to be mathematically tedious when the number of craft increases. As a simplification for rapid development of scenarios, the SAVAGE project team previously developed a Waypoint Interpolator prototype. This was employed to create the known track of the COLE and for the possible tracks of the terrorist boat and other craft (i.e., fixed tracks for planning or reconstruction, separate from introduction of agent or human control of entity movements).

Perhaps one of the most useful components developed within the SAVAGE project during the reconstruction of the attack on the COLE was the Digital Virtual Display (DVD) Prototype (Figure 8). Before its development, testing the reconstruction of scenes was extremely tedious when the developer had to wait a prolonged time period to observe critical events. Using the DVD controller, a user has multiple options by which to view a scene. The user can play, pause, fast forward, rewind, or even dynamically move the scenario forward or backward in time using a slider located on the bottom of the controls. This is one of the advantages of reconstructing events with an interactive 3D tool – the user can analyze events from a spatial or temporal perspective in various ways that might provide new or quicker insights.
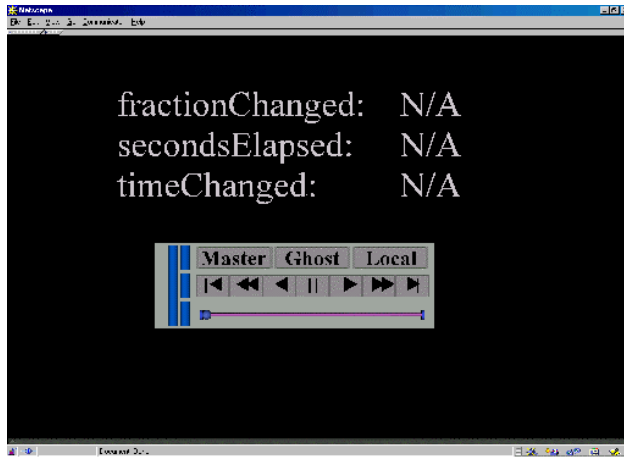
**Figure 8**. Digital Video Display (DVD) prototype example.

Static reconstruction of experiments allows us to examine events as they happen, but the capability to truly leverage current visualization technologies in this arena lies within the ability to dynamically simulate events and play "what if" scenarios. Coupled with the use of agent technologies, the analyst can now explore a much greater range of questions and possibilities before expending vital funds and other resources in an actual experiment.

For the planned AT/FP LOE, a 2D planning tool (see Figures 9 and 10) was also developed to facilitate craft positioning and movement planning. A Web3D visualization of the scenario is then generated automatically from the planning tool input. To examine the planned scenario, a multi-layered intelligent agent approach is used (Figures 11 and 12). The initial layer can be considered as a "hands-off" approach wherein the planner defines the setup for the experiment, initiates the run, and views the computer-driven offensive and defensive agents playing out the simulation. The analyst can choose to run multiple scenarios with the same starting parameters without the visual display in order to more rapidly gather statistical data on the planned conditions. From this, the analyst can gain insight to various tactical parameters such as optimal picket boat placement against a surface threat, range parameters for identification and possible engagement of small craft, and redundancies required for effective defense, and then decide how to best arrange the naval forces taking part in the LOE in order to test the targeted equipment or doctrine without losing valuable experiment time.

Alternatively, a "human-in-the-loop" layer is also incorporated to allow the planner to play the role of the defense against the computer-driven offense, or to play the offense against the computer-driven defenses. In the Web-based environment, it is even possible to have multiple human analysts control various craft in the scenario, permitting analyst-versus-analyst interactions for examination of the scenario possibilities.
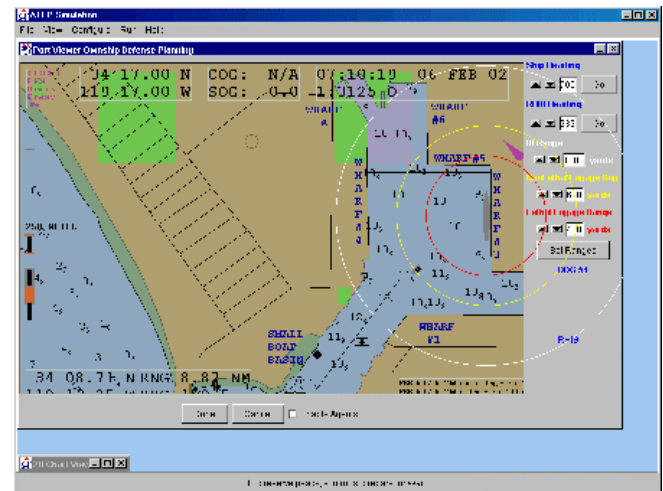


**Figure 9**. Depiction of simulation 2D setup for a LOE to be conducted in Port Hueneme, California.
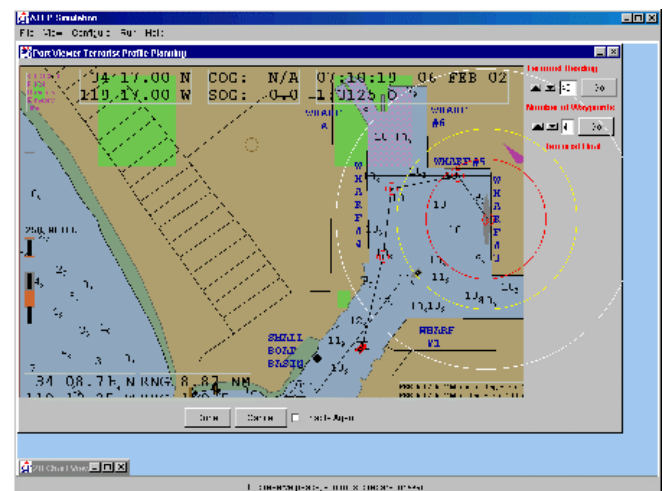


**Figure 10**. Depiction of simulation threat profile definition by the end-user.

Through these various layers of control, an analyst can more thoroughly examine alternative

experiment set-ups and then demonstrate the planned approach to other planners/sponsors. Additionally, new weapons and their employment can be simulated with enough fidelity to aid in the overall study.  In this case, a specific non-lethal weapon under consideration for employment in the FP LOE was simulated in order to gain insight to potential employment possibilities and drawbacks.
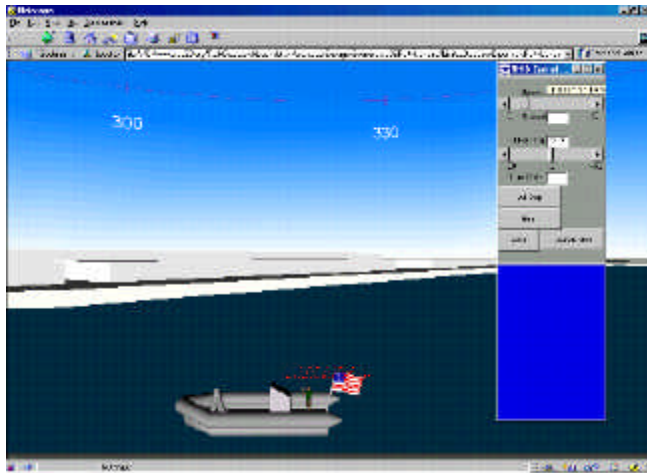


**Figure 11**. Graphical representation of defending RHIB in user control mode. Depicted is a conceptual representation of a non-lethal net entanglement system on the forward end of the RHIB.
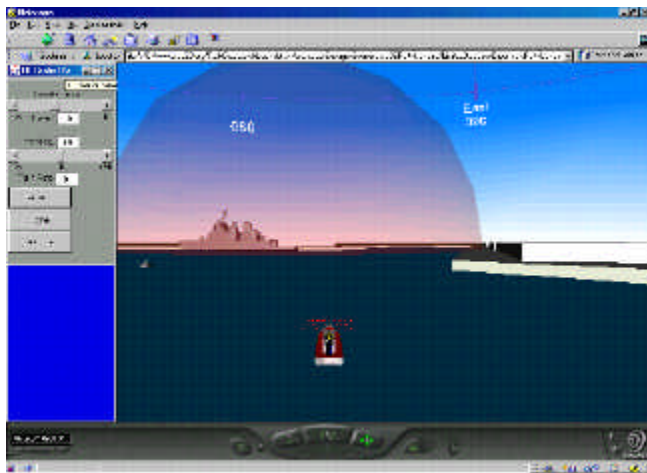


**Figure 12**. Graphical representation of attacking surface craft in agent control mode.  Red (shaded) sphere depicted in background represents the High Value Unit's (DDG) lethal engagement range.

# FUTURE RESEARCH DIRECTIONS FOR WEB3D APPLICATIONS

The Extensible 3D (X3D) specification is an exciting new area of work, expressing the geometry and behavior capabilities of VRML using the Web-compatible tagsets of the Extensible Markup Language (XML). Scene graph, nodes and fields respectively correspond to document, elements and attributes in XML parlance. The X3D Task Group is designing and implementing the next-generation Extensible 3D graphics specification (www.web3D.org/x3d.html). XML benefits are numerous: customized metalanguages for structuring data, easily read by humans and computer systems, validatable data constraints, etc. XML is license-free, platform-independent and well-supported (Bos 2001). Together these qualities can ensure that the VRML ISO standard is extended to functionally match the emerging family of next-generation XML-based Web languages.

Web3D is a powerful medium for construction, dissemination, and employment of dynamic, interactive, multi-user virtual environments. Used for simplistic, rapid, low-cost visualization or integrated with sophisticated software for agent-based behaviors and physically-based models, Web3D is proving to be an effective tool for providing insights into real-world scenario planning and reconstruction. The technology is helping analysts more effectively assess tactics, techniques, procedures, weapons, and other systems that can benefit today's and future warfighters. Research is needed in determining optimal methodologies for integration and execution of agent-based simulation in the scenarios, and for analysis of execution outcomes, to facilitate user efforts in configuring scenario conditions for analysis.

The Department of Defense is currently converting standard United States Message Text Format (USMTF) messages into XML (XML-MTF, 2001). Research at NPS has shown the potential of autotranslating 3D models directly from USMTF operations-order messages (Murray and Quigley, 2000; Nicklaus 2001) and from tactical communications planning systems (Laflam, 2000, and Hunsberger, 2001). In a collaborative effort with the Naval Undersea Warfare Center (NUWC) and NPS, the Institute for Defense Analysis (IDA) has created an XML-based Land Command and Control Information Exchange Data Model (LC2IEDM; IDA, 2000) to form a basis for interoperability among command and control systems. NUWC is extending this model to also support the Maritime domain. Work is needed to enable greater automation in this process, both through greater refinement in the operational messaging process and in the ability of software to extract necessary visualization requirements and components from the operational message (e.g., terrain and environmental data for the scenario location, behaviors for the scenario participants, 3D models for the entities to be represented).

The above work in creating a common "dialect" for autogenerating Web3D content from operational messages is complemented by efforts underway in the Department of Defense to define a common XML tagset for scenario descriptions to facilitate interoperability among simulation systems and command and control systems. Two efforts are being monitored closely for applicability to the SAVAGE project: (1) Joint Simulation System (JSIMS) Common Control WorkStation (CCWS) scenario generation (JSIMS, 2000); (2) DMSO dynamic scenario builder initiatives (Lacy, Stone, and Dugone, 1999, and Lacy and Dugone, 2001). It is expected that these efforts will provide a set of abstractions describing scenario elements, from which an XML-based tool can be configured to enable a user to construct the scenario in a hierarchical manner with time sequenced behaviors. The resulting XML file can then be manipulated in any number of ways, including transformation into VRML structures for 3D visualization. Clearly, representation schemes for asymmetric warfare, military operations in urban terrain, information warfare, and other "nontraditional" battlespaces present a significant research challenge.

The SAVAGE project is a long-term research program seeking to push the frontier of Web-based 3D scenario authoring and visualization. In addition to the numerous models and case-study examples previously described, directions for the work include:

- Expanding the palette of models and events that can be inserted into a scenario, including representation of control measures and other non-physical concepts in the battlespace.

- Creating scenarios of greater complexity depicting the interplay of represented land, air, sea, and littoral objects and operations. Include the interaction of operations with control measures.

- Creating branching flows in the scenario script to present decision points that engage the user in the unfolding scenario.

- Investigating assignment of behaviors to scenario objects; for example, from XML libraries of pre-scripted actions (see Lacy and Pearman, 2000) with adaptation mechanisms to the current situation.

- Developing techniques for rapidly generating battlespace terrain, to include representation of built-up areas and vegetation cover, for use in the Web3D environment.

- Automating extraction of scenario information from doctrinal operations orders and plans.

- Integrating Web3D graphics into an overarching Web-based Modeling and Simulation framework

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